Protection of Marine Riparian Functions in Puget Sound

City of Burien Science Forum

June 14, 2010

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Washington Department of Ecology

Document available

- Produced by Washington Sea Grant under contract to WDFW & guided by subcommittee of interagency Aquatic Habitat Guidelines (AHG) Working Group
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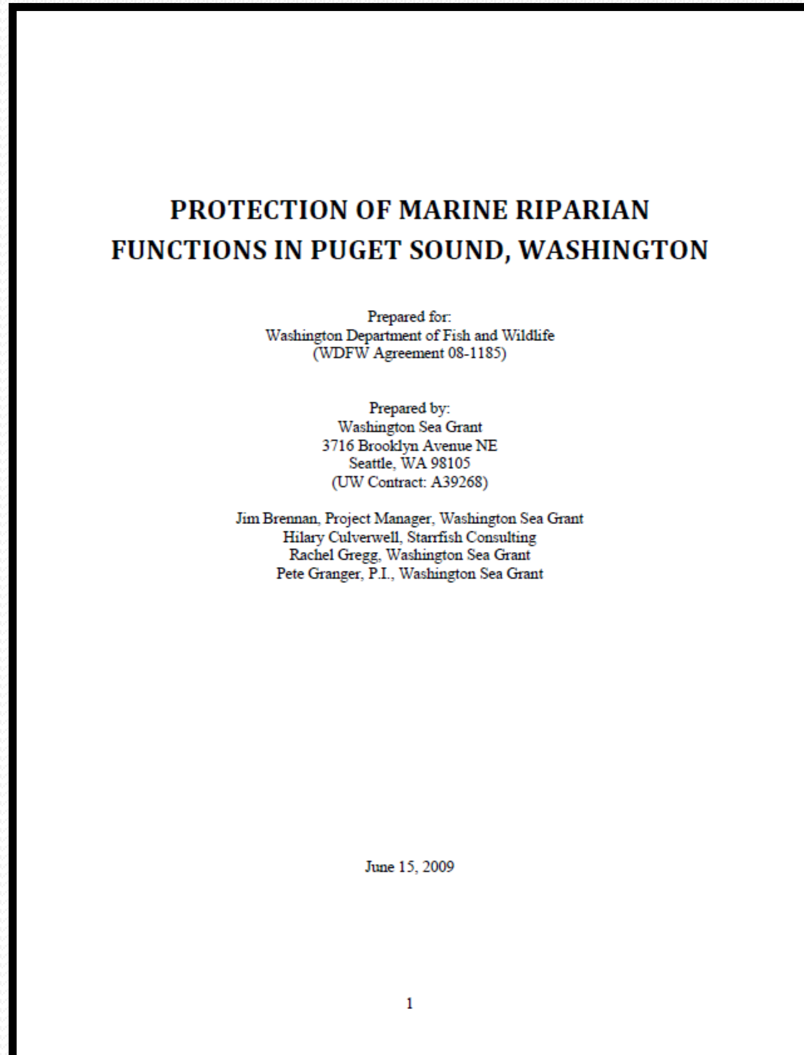
- Reviewed by state agencies through AHG Working Group
- Reviewed by Federal and local government scientists



PROTECTION OF MARINE RIPARIAN FUNCTIONS IN PUGET SOUND, WASHINGTON

Prepared for:
Washington Department of Fish and Wildlife
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June 15, 2009

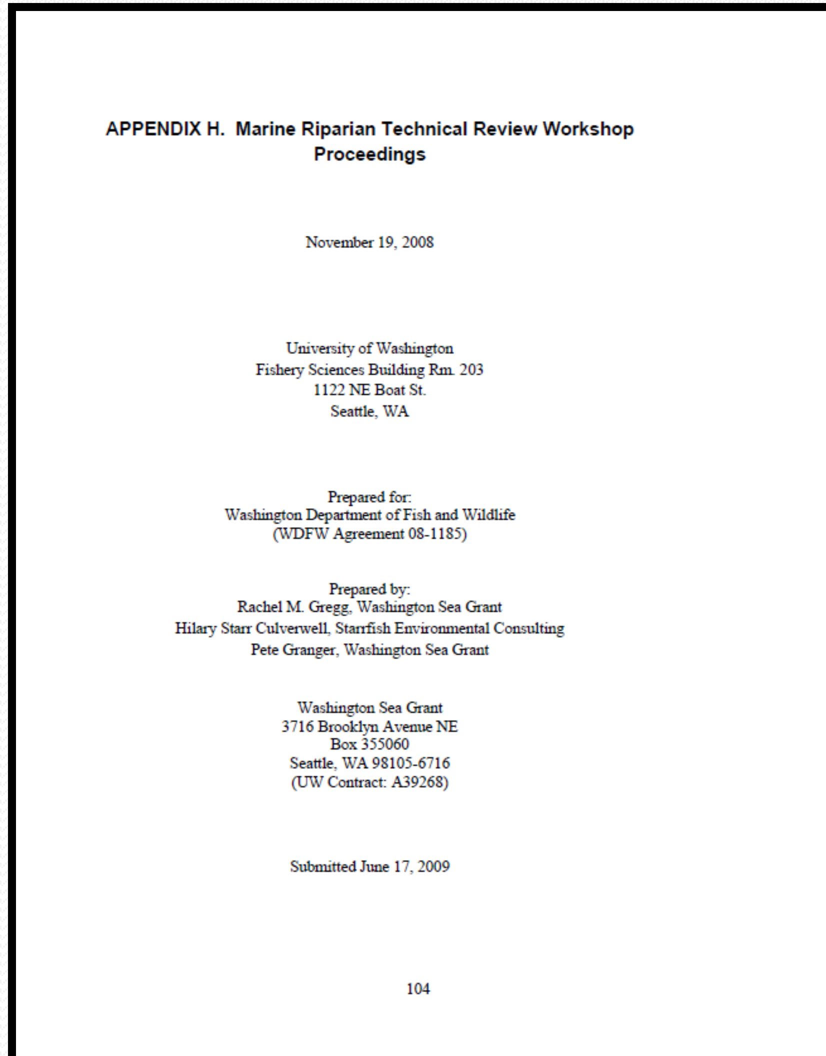
1

wdfw.wa.gov/hab/ahg/riparian_protection.htm

Technical Review Workshop

Participants:

- Jim Agee, UW
- Derek Booth, UW; Stillwater Sciences
- Jim Brennan, WA Sea Grant
- Randy Carman, WDFW
- John Marzluff, UW
- David McDonald, Seattle Public Utilities
- Bob Naiman, UW
- Michael Pollock, NMFS
- Tim Quinn, WDFW
- Steve Ralph, Stillwater Sciences
- Si Simenstad, UW
- Kathy Taylor, Ecology
- Dan Tonnes, NMFS
- Steve Toth, independent consultant



APPENDIX H. Marine Riparian Technical Review Workshop Proceedings

November 19, 2008

University of Washington
Fishery Sciences Building Rm. 203
1122 NE Boat St.
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Prepared for:
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Submitted June 17, 2009

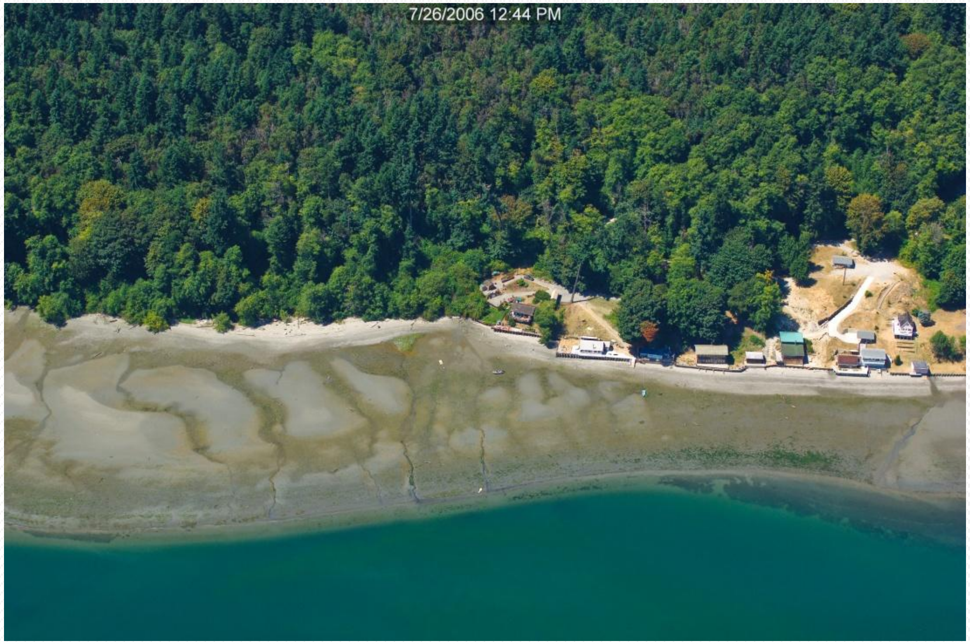
104

4 researchers reviewed over 300 scientific and technical documents:

- Jessi Kershner, UW School of Marine Affairs
  - Slope stability, erosion control, hydrology
- Rachel M. Gregg UW; Washington Sea Grant
  - Water quality, litter fall/organic matter inputs
- Dan Tonnes UW School of Marine Affairs; NOAA Fisheries
  - Large Woody Debris
- Jim Brennan UW; Washington Sea Grant
  - All Functions

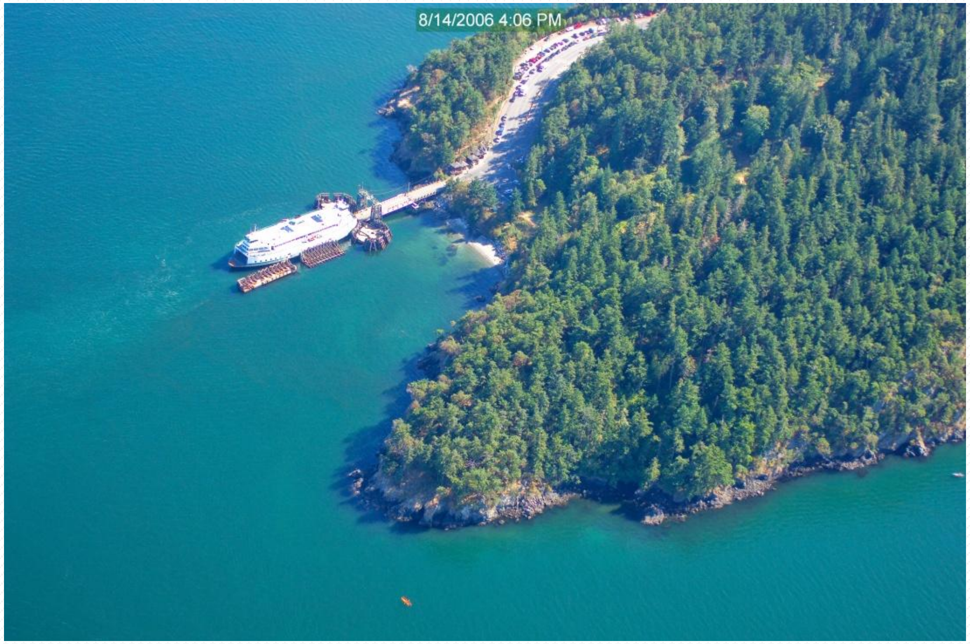
Protection of Marine Riparian Functions in Puget Sound, Washington

Contains a literature review and synthesis of scientific and technical information on riparian areas and summarizes recommendations to help protect marine riparian functions.



Contents

- Introduction
- Description of the methodology used to compile information
- Overview of the importance of marine riparian areas
- Overview of physical and ecological attributes of Puget Sound shorelines

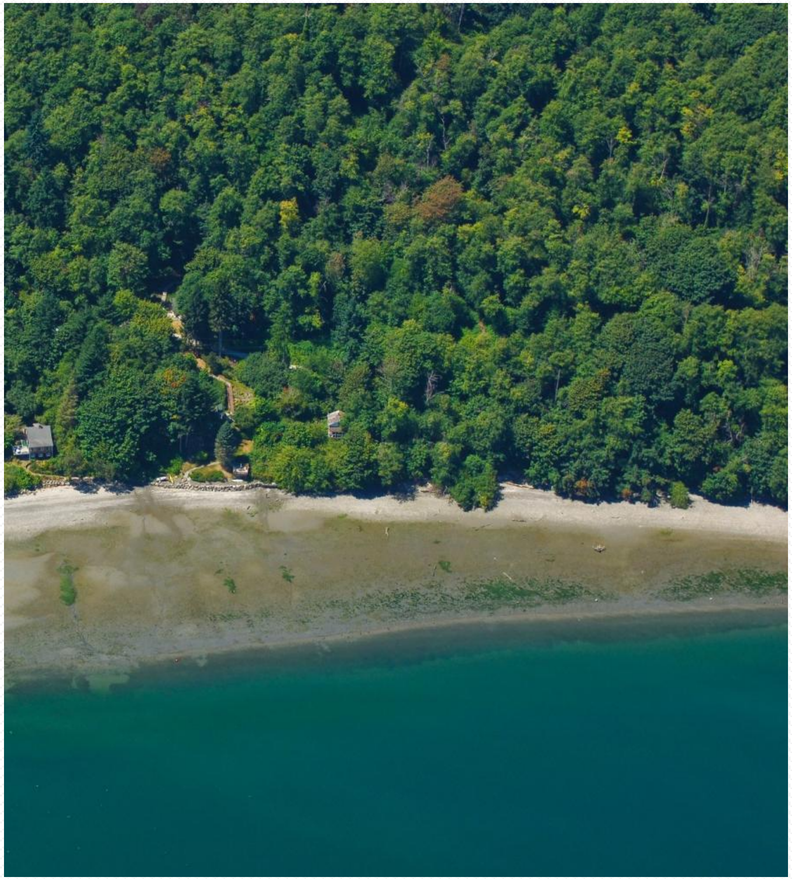


Contents (continued)

- Description of the seven riparian functions selected for review and recommendations for protecting these functions
- Description of impacts to riparian functions from activities associated with urbanization, agriculture and forest practices
- Summary of recommendations to protect and minimize disturbance to marine riparian functions

The document is focused on the following seven riparian functions:

- Water quality
- Fine sediment control
- Shade/microclimate
- Large woody debris (LWD)
- Litter fall/organic matter inputs
- Wildlife
- Hydrology/slope stability



Water Quality

Water Quality

Riparian areas provide water quality benefits through a variety of mechanisms including:

- Infiltration and corresponding reduction of surface runoff rates/volumes;
- Intercepting nutrients, fine sediments and associated pollutants from surface water runoff;
- Binding dissolved pollutants with clay and humus particles in the soil;
- Conversion of excessive nutrients, pollution, and bacteria from surface and shallow groundwater into less harmful forms by riparian vegetation; and
- Regulating water temperature.

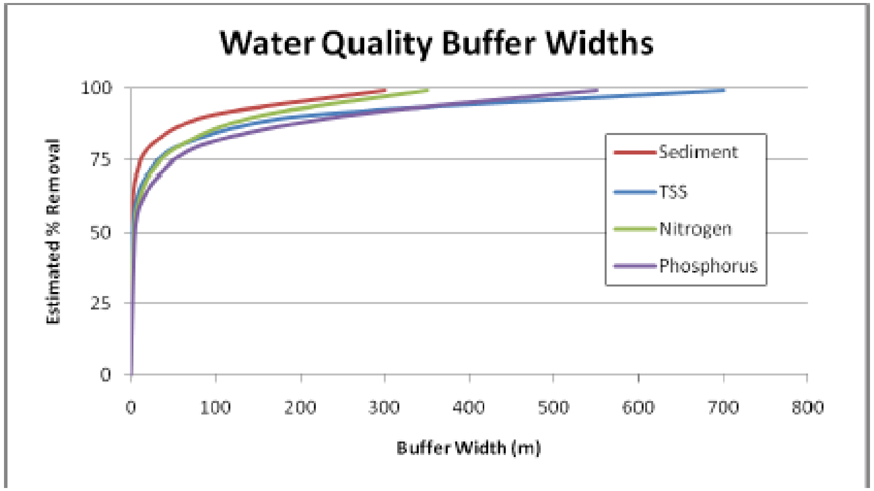


Figure 1. Contaminant removal effectiveness of four water quality parameters at various buffer widths (adapted from Desbonnet et al. 1995).

Table 1. Summary data adapted from Desbonnet et al. (1994, 1995) used to generate generalized curve for removal effectiveness of various pollutants at different buffer widths. This data is identical to Desbonnet et al (1995) with the exception of the zero point which we added for illustrative purposes.

% Removal	Buffer Width in Meters (ft)			
	Sediment	TSS	Nitrogen	Phosphorus
0	0	0	0	0
50	0.5 (1.6)	2 (6.6)	3.5 (11)	5 (16)
60	2 (6.6)	6 (20)	9 (30)	12 (39)
70	7 (23)	20 (66)	23 (75)	35 (115)
80	25 (82)	60 (197)	60 (197)	85 (279)
90	90 (296)	200 (656)	150 (492)	250 (820)
99	300 (984)	700 (2297)	350 (1148)	550 (1804

Conclusions from review of the literature for water quality functions:

Soil characteristics, slope and vegetation cover type are the most important determinants of buffer effectiveness to protect water quality. To maximize the buffer's effectiveness to remove contaminants, the following actions are recommended in order of priority:

- *Retain, restore, or enhance vegetation, particularly native vegetation.*
- *Manage drainage to ensure that water is moving evenly through the buffer to maximize retention time and infiltration, rather than flowing through pipes, culverts, rills, or other conveyance mechanisms. Avoid routing drainage to adjacent streams that may transect marine riparian areas.*

Conclusions from review of the literature for water quality functions:

- *Avoid the use of pollutants (petroleum, toxics, pesticides, etc) in or near riparian areas.*
- *Avoid construction of impervious surfaces and septic tank drain fields in riparian areas. Manage agricultural and pasture lands to minimally disturb buffers.*
- *Limit or prohibit the application of pesticides and herbicides in or near riparian areas.*
- *Avoid disturbance (e.g., grading, compaction, removal) of native soils.*

Fine sediment control

Fine Sediment Control

Fine sediments originate from a number of terrestrial sources, both natural and anthropogenic, however, the focus of this section is fine sediments originating from development, forestry, and agriculture, which can increase fine sediment delivery **beyond normative rates**

- Riparian vegetation intercepts rainfall energy, helping prevent soil compaction;
- Roots and soils help bind and restrain soil particles and increase sheer strength of the soil;
- Vegetation slows surface runoff allowing for increased localized sediment deposition and decreasing off-site transport;
- Porous and permeable soils improve water absorption reducing surface flow; and
- Transpiring vegetation helps moderate soil moisture levels, which increases infiltration and decreases saturation that leads to increased surface water run-off.

Conclusions from review of the literature for fine sediment control functions:

Review suggests that:

- *The range of buffer widths that met a minimum 80% effectiveness for this function was 25-91 meters (Appendix G).*

- *Wider buffers are needed in areas with steep slopes.*

- *Site specific conditions should be considered when determining buffer width (e.g. soils, vegetation type and density, upland/adjacent land uses, and loading).*

Table 2. Summary data adapted from Desbonnet et al. (1994, 1995) used to generate generalized curve for removal effectiveness of various pollutants at different buffer widths. This data is identical to Desbonnet et al (1995) with the exception of the zero point which we added for illustrative purposes. Note that this table is identical to Table 1.

% Removal	**Buffer Width in Meters (ft)**			
	Sediment	TSS	Nitrogen	Phosphorus
0	0	0	0	0
50	0.5 (1.6)	2 (6.6)	3.5 (11)	5 (16)
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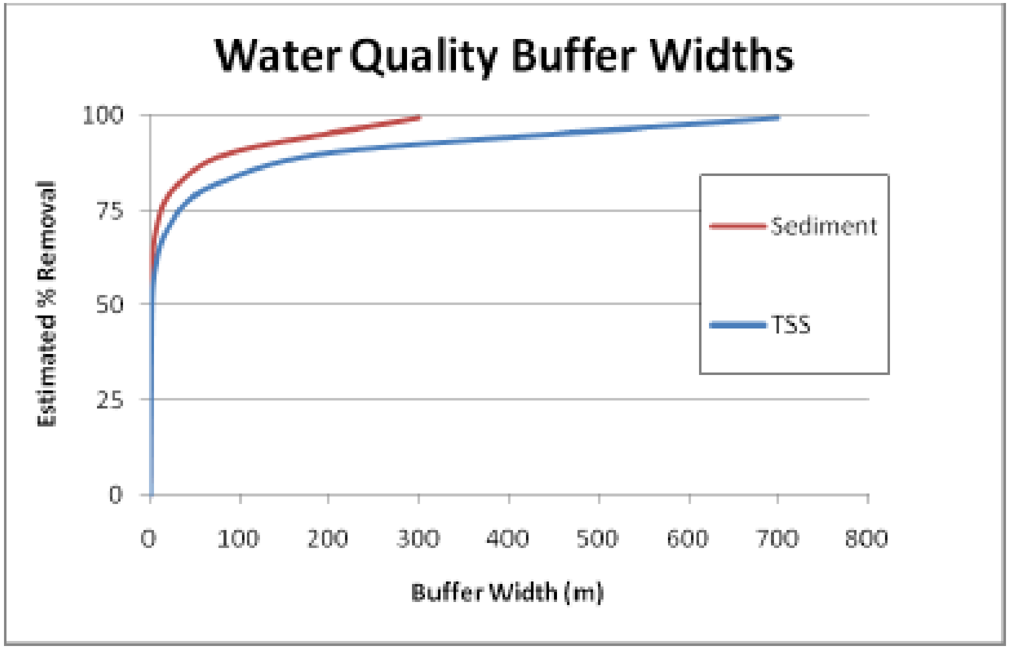

Figure 2. Sediment and total suspended sediment (TSS) removal effectiveness of two water quality parameters at various buffer widths (adapted from Desbonnet et al. 1995).

Important notes regarding fine sediment control:

Science panelists at the technical workshop noted that:

- *maintaining natural erosion and sediment transport processes is critical to maintaining Puget Sound beaches and much of the sediment nourishing these beaches originates in marine riparian areas.*

- *delivery of this sediment is facilitated by natural driving forces (wind and wave action, bluff saturation, leading to slope failures) and it is very important to maintain these natural sediment inputs.*

- *A current threat to marine riparian systems from human activity is the reduction of sediment inputs by armoring shorelines and disrupting natural erosion of bluffs.*

Shade/Microclimate

Shade/Microclimate

Science panelists agreed that:

- Shade is an important function for a number of organisms in the upper intertidal areas during low tide (when exposed upper intertidal areas are subject to heating

- Shade in marine environments is potentially less important in moderating the temperature of the water body than shade in freshwater systems -- Puget Sound water temperatures as a whole are unlikely to be affected much by shade cast by riparian vegetation

Table 3. Data used to create generalized curve in Figure 3 indicating percent of riparian shade function occurring within varying distances from the edge of a forest stand (adapted from FEMAT 1993).

Effectiveness (%)	Buffer Width (SPTH)	Buffer Width SPTH m (ft)
0	0.00	0 (0)
10	0.07	4 (14)
20	0.15	9 (30)
30	0.22	13 (44)
40	0.29	18 (58)
50	0.36	22 (72)
60	0.42	26 (84)
70	0.50	31 (100)
80	0.60	37 (122)
90	0.73	45 (146)
93	0.80	49 (160)
95	1.00	61 (200)

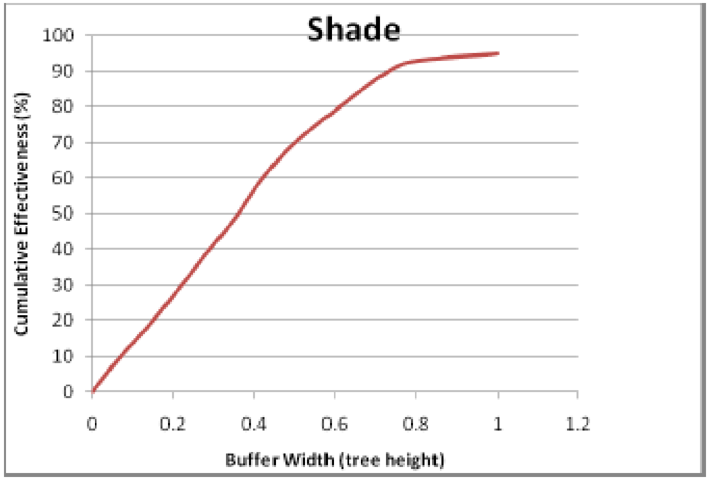

Figure 3. Generalized curve indicating percent effectiveness of riparian shade occurring within varying distances from the edge of a forest stand. Tree height (SPTH) is used to indicate buffer width where one SPTH = 61 meters (200 ft) (adapted from FEMAT 1993).

Conclusions from review of the literature for shade/microclimate functions:

Review suggests the following actions to maximize the buffer's effectiveness to provide the shade function:

- *Avoid disturbance to native vegetation in riparian areas, especially nearer the water's edge.*
- *Retain, restore, and enhance mature trees and a multi-layered canopy and understory of native vegetation at sites that support these types of plant communities.*

Conclusions from review of the literature for shade/microclimate functions:

- *Ensure that riparian areas can be maintained in mature, native vegetation through time.*
- *Prevent modifications to banks and bluffs (e.g., armoring) that could disrupt natural processes (such as soil creep, development of backshore and overhanging vegetation, recruitment of wood and other organic matter to riparian area including beaches and banks.)*
- *Prohibit cutting and topping of trees and avoid "limbing" where possible.*

Large Woody Debris

Large Woody Debris

- In marine environments, LWD (also known as 'driftwood') originates from both freshwater and marine riparian sources. Marine riparian areas contribute LWD to shorelines through natural recruitment processes, including windstorms, fires, wave action, and landslides (NRC 1996).

- Most of Puget Sound's bluffs are naturally unstable and landslides are a common occurrence throughout the region (Johannessen and MacLennan 2007).

Large Woody Debris

- Several studies conducted in Puget Sound have shown that LWD has a significant effect on substrate temperatures (Higgens et al. 2005; Rice 2006; Tonnes 2008)
- Detritus entrained in driftwood is linked with increased invertebrate biomass which, in turn, supports higher level prey for species such as shorebirds.
- Marine LWD also provides structural support for vegetation similar to nurse logs in upland settings.

Large Woody Debris

- Increased vegetation provided by driftwood also increases primary productivity and increases structural complexity for fish and wildlife.
- Buffer width effectiveness is strongly influenced by site conditions (such as slope) and the potential height of mature trees.
- A number of studies and reviews of riparian buffers note that, in addition to considering the benefits of LWD in adjacent water bodies, it is important to consider LWD benefits within the terrestrial environment, specifically for its contribution of ecological functions e.g., nurse logs, habitat, nutrient recycling, and helping maintain soil moisture.

Table 4. Approximated data used to create generalized curve (Figure 4) indicating percent of LWD recruitment function occurring within varying distances from the edge of a forest stand (adapted from FEMAT 1993).

Effectiveness (%)	Buffer Width (SPTH)	Buffer Width m (ft)
0	0.00	0 (0)
10	0.07	4 (14)
20	0.15	9 (30)
30	0.22	13 (44)
40	0.29	18 (58)
50	0.36	22 (72)
60	0.42	26 (84)
70	0.50	31 (100)
80	0.61	37 (122)
90	0.73	45 (146)
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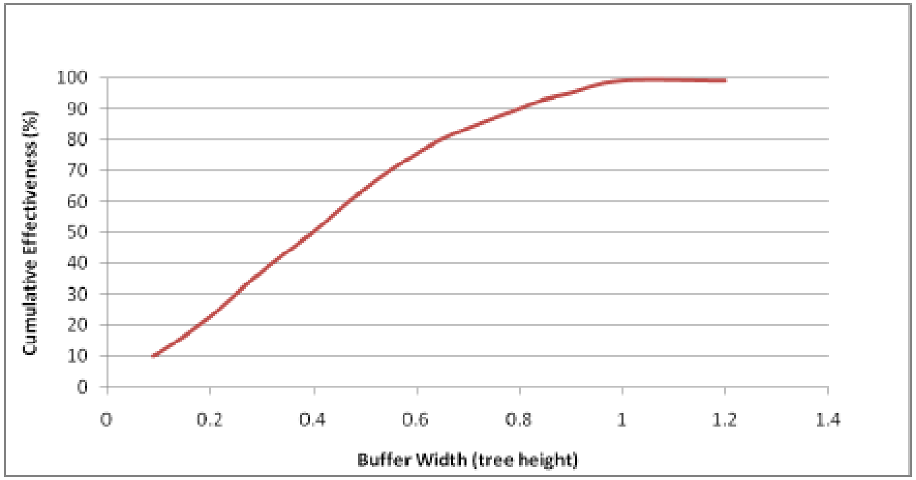


Figure 4. Generalized curve indicating percent effectiveness of LWD recruitment from riparian areas occurring within varying distances from the edge of a forest stand. Tree height (SPTH) is used to indicate buffer width. One SPTH = 61 meters (200 ft) (adapted from FEMAT 1993).

Conclusions from review of the literature for large woody debris functions:

- *To maximize buffer's effectiveness to provide the LWD function, the following actions are recommended:*
- *Avoid human disturbance in riparian areas.*
- *Allow for the accrual of drift wood and other upland sources of LWD on beaches and shorelines.*
- *Protect, restore, and enhance marine riparian trees to help ensure a long-term source of LWD.*

Conclusions from review of the literature for large woody debris functions:

- *Provide buffers that allow for long-term source and recruitment of trees (LWD) as shorelines retreat, or as a result of soil creep and landslides, and increasing sea levels.The range of buffer widths that met a minimum 80% effectiveness for this function was 17-38 meters (Appendix G).*

- *Buffer width effectiveness is strongly influenced by site conditions (such as slope) and the potential height of mature trees.*

- *A number of studies and reviews of riparian buffers note that, in addition to considering the benefits of LWD in adjacent water bodies, it is important to consider LWD benefits within the terrestrial environment, specifically for its contribution of ecological functions e.g., nurse logs, habitat, nutrient recycling, and helping maintain soil moisture.*

Litter Fall/Organic Matter Inputs

Litter Fall/Organic Matter Inputs

- Riparian vegetation provides litter that serves as habitat and food for fishes and aquatic invertebrates and influences the amount and type of terrestrial invertebrates that fall into aquatic systems.

- Terrestrial invertebrates serve as a major food source for fishes (including salmon) birds, mammals, reptiles, and amphibians. Terrestrial insects have recently been shown to be a large component of the diet of juvenile salmonids residing in nearshore waters of Puget Sound.

- Nutrient exchange occurs in two directions from the terrestrial to aquatic systems and vice versa. Examples of nutrient-energy exchange (marine to terrestrial and terrestrial to marine) include:
  - Atmospheric input via wet or dry deposition, which can occur through fires, intensive farming and agricultural activities, and wind erosion.
  - Lateral transfers of nutrients through tidal and wave action, including microalgae and macroalgae washed ashore.

Litter Fall/Organic Matter Inputs

- Decomposing secondary consumers, such as juvenile Pacific herring, Pacific sand lance, longfin smelt, surf smelt, sole, salmon, seabirds, and marine mammals, which also contribute nutrients. For example, Pacific salmon nutrients are deposited by predators and scavengers in excreta, or as carcasses and skeletons

- Secondary consumers can transport nutrients to upland areas, facilitating nutrient and energy exchange between terrestrial and aquatic food webs (e.g. eagles eating fish).

Table 5. Approximated values for cumulative effectiveness of buffer width for litter fall/organic matter inputs used to create Figure 5, based on the original FEMAT curve.

Effectiveness (%)	Buffer Width (SPTH)	Buffer Width m (ft)
0	0	0
10	0.04	2.4 (8)
20	0.08	4.9 (16)
30	0.12	7.3 (24)
40	0.17	10.3 (34)
50	0.22	13.4 (44)
60	0.27	16.5 (54)
70	0.33	20.0 (66)
80	0.40	24.4 (80)
90	0.50	30.5 (100)
95	0.65	40.0 (130)
98	0.90	55.0 (180)

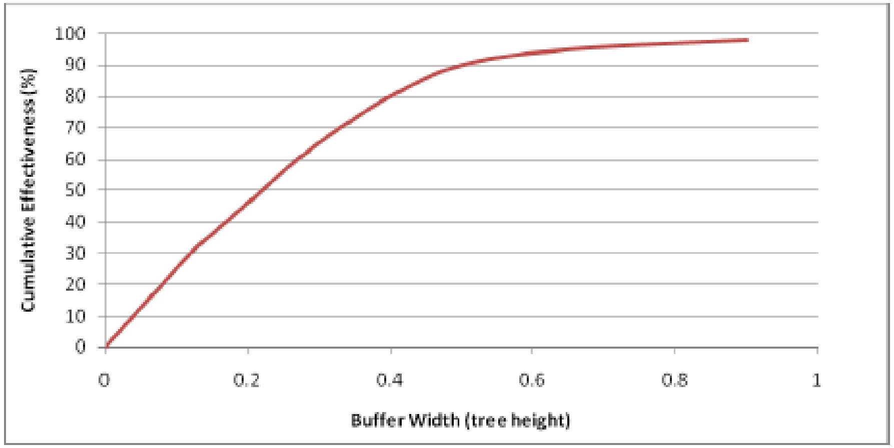


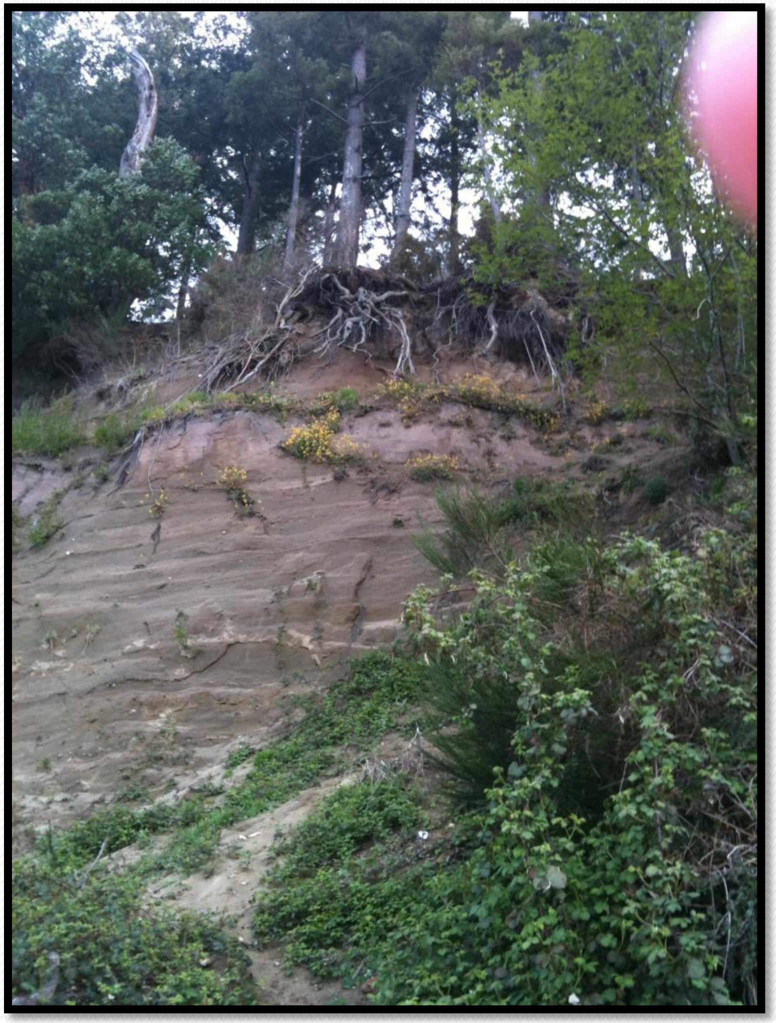
Figure 5. Effectiveness of riparian litter fall/organic matter input as a function of distances from the water's edge (adapted from FEMAT 1993) where one site potential tree height is approximately 60 meters or 200 ft.

Conclusions from review of the literature for litter fall/organic inputs

To maximize the riparian function for litter fall/organic matter inputs the following actions are recommended:

- *Maintain native riparian vegetation in the riparian area.*
- *Avoid human disturbance to vegetation.*
- *Allow for natural succession of plant communities and maintain sources and accumulations of organic matter within riparian areas and on beaches.*

Hydrology/Slope Stability



Hydrology/Slope Stability

Riparian vegetation plays an important role in affecting hydrologic processes and slope stability in the following ways (adapted from Gray and Leiser 1982):

- ***Interception:*** *Foliage and plant litter absorb the energy of precipitation, reducing direct* impacts on soil.
- ***Restraint****: Root systems bind soil particles and blocks of soils, and filter sediment out of runoff.*
- ***Retardation:*** *Plants and litter increase surface roughness, and reduce runoff volume and velocity, thereby reducing channelization.*
- ***Infiltration:*** *Roots and plant litter help maintain soil porosity and permeability.*
- ***Transpiration:*** *Plants absorb moisture, delaying the onset of soil saturation and surface runoff.*

Hydrology/Slope Stability

- ***Root Reinforcement:*** *Roots mechanically reinforce soil by transferring shear stresses in the soil to tensile resistance in the roots.*

- ***Soil Moisture Depletion:*** *Interception of raindrops by foliage and evapotranspiration limit buildup of soil moisture.*

- ***Buttressing and Arching:*** *Tree trunks can act as buttress piles or arch abutments in a slope, counteracting shear stresses.*

- ***Surcharge:*** *The weight of vegetation on a slope may exert a destabilizing down slope stress and a stress component perpendicular to the slope that increases resistance to sliding.*

- ***Root wedging:*** *Roots invade cracks and fissures in soil or rock that could add restraint stability or cause local instability by wedging action.*

- ***Wind throw:*** *Strong winds cause trees to blow down that can disturb slope soils*

Table 6. Setback distances (in ft) from Griggs et al 1992 as cited in Macdonald and Witek (1994) for different bluff heights at various levels of stability where geologic stability for 50-years cannot be demonstrated.

Bluff Height (ft)	Stable (1:1)(45^{0})	Moderately Stable (2:1)(30^{0})	Unstable (1:1)(45^{0})+ (2:1)(30^{0})
20	20	40	60
40	40	80	120
60	60	120	180
80	80	160	240
100	100	200	300
120	120	240	360
140	140	280	420
160	160	320	480
180	180	360	540
200	200	400	600

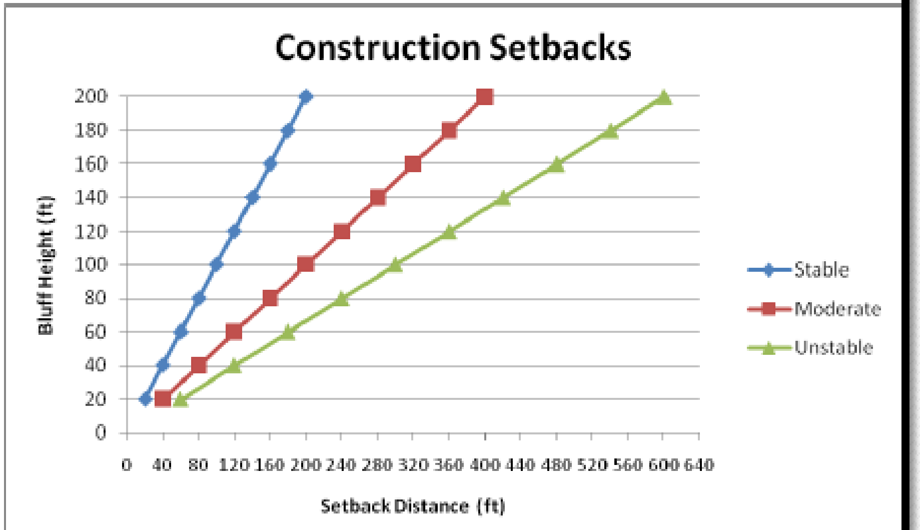


Figure 6. Construction setbacks for different bluff heights at various levels of stability, where geologic stability for 50-years cannot be demonstrated (after Griggs et al 1992 as cited in Macdonald and Witek 1994).

Important notes regarding hydrology/slope stability

- Landforms and geology can be more important for slope stability than buffer width. For example, in the San Juan Islands, there can be a 45 degree slope on basalt form that can be very stable.

- Geomorphic shore form is an important consideration – geologic legacy, landscape position, density, slope, etc.

- Upslope alterations can be contributing factors to slope instability.

- It is important to consider flow paths; for example, slope stability may be associated more with altered upland drainage patterns or precipitation patterns. Buffer width versus landform may be the most important factor. For example, steeper slopes, particularly those with underlying geologic instability, require wider buffers.

Conclusions from review of the literature for hydrology/slope stability

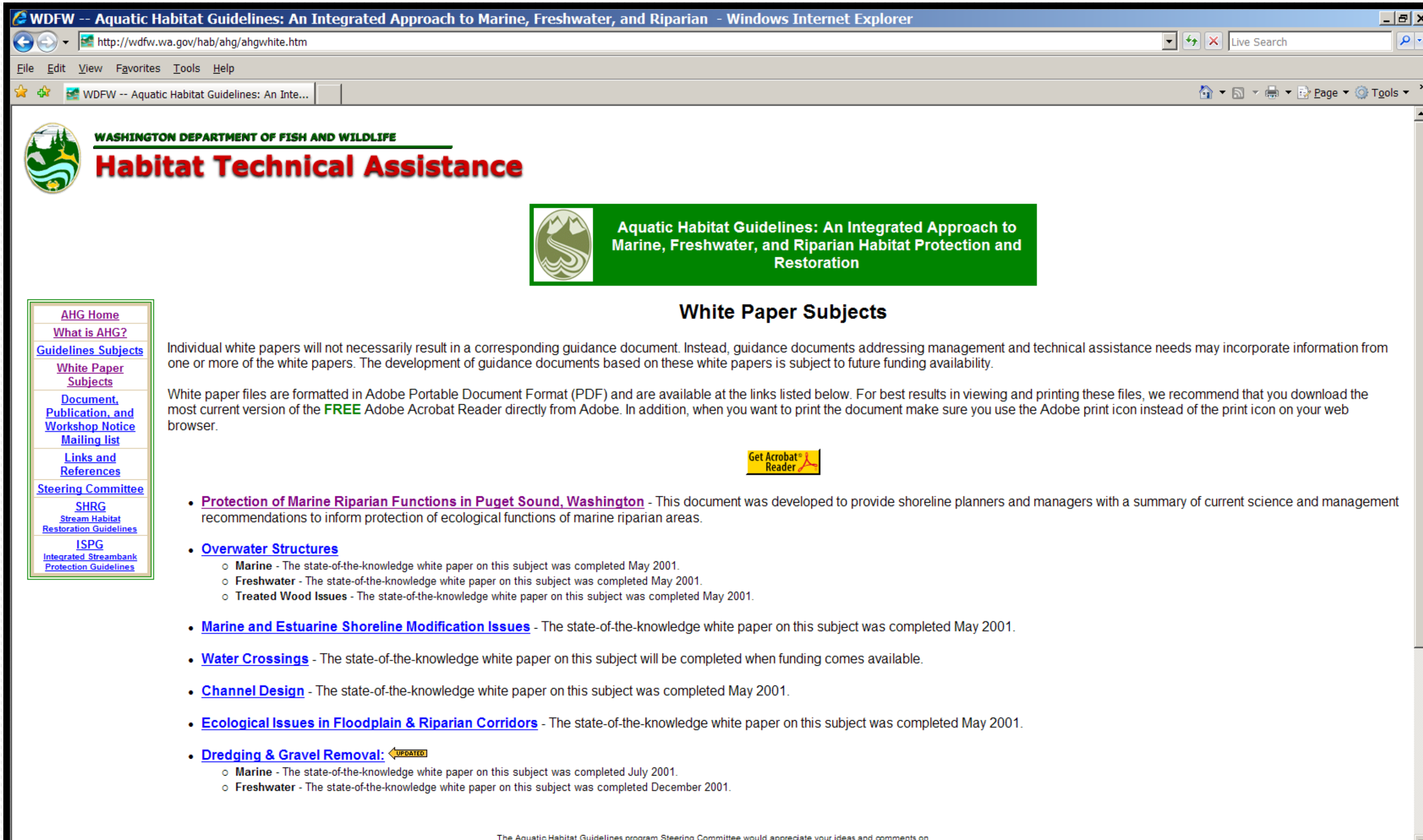
- No riparian function curve was developed for this section, due to the high variability of site specific conditions that may be encountered and the lack of summary data that could be generally applied.
- To maximize the buffer's effectiveness to maintain hydrologic functions and slope stability, the following actions are recommended:
- Avoid development near naturally eroding bluffs.
- Avoid engineering approaches that encroach on buffers to create more stable slope conditions.
- Avoid impervious surfaces and compacted soils.
- Maintain riparian vegetation especially on steep slopes to prevent excessive erosion and allow for evapotranspiration.
- Avoid 'loading' of bluffs whereby excessive moisture (from irrigation, septic fields, impervious surfaces, and other sources of water) can exacerbate the instability and erosion potential of the site.

Wildlife

Wildlife

- Riparian areas provide the resources and structure to meet important life history requirements such as feeding, roosting, breeding, refuge, migration corridors and clean water for a variety of wildlife species.
- Wildlife species have adapted to the natural processes, structure, and functions of marine riparian areas and have also played an important role in shaping the structure and character of riparian areas. For example, many birds and mammals that breed and rear in upland areas forage in intertidal areas. Thus, these species provide marine derived nutrients to uplands in the form of feces and carcasses. These marine derived nutrients play an important role in forest ecosystem health

http://wdfw.wa.gov/hab/ahg/



Appendix C

Table showing summary of buffer recommendations for each buffer function from selected review documents.

- Study
- Year
- Study type
- Basis for Buffer Recommendation
- Buffer Composition
- Buffer Range
- Minimum Buffer Width Recommendation
- Key comments and findings

APPENDIX C. Literature cited for seven buffer functions

Study	Year	Study type	Review or original research	Pollutant of focus	Buffer Composition	Buffer range	Minimum Width Recommendation[1]	Key findings and comments
City of Boulder PDS and Biohabitats, Inc.	2007	Wetlands and streams	Review of science and regulatory approaches to buffers	Phosphorus	Not specified	Not specified	30 m (100 ft) for steep slope, 50 ft for shallow slope	Base minimum recommendations on CWP/EPA 2005.
				Nitrogen			30 m (100 ft)	Buffer composition not specified, but recommends grass and trees (best for sediment- bound nutrients, pesticides, and pathogens).
				Biocontaminants, pesticides			15 m (50 ft)	
Goates	2006	Freshwater streams	Review of adequacy of standard 30m buffers in protecting wildlife	Not specified	Not specified	15-40 m (49 – 131 ft) (Phillips 1989)	Not specified	
				Soluble nitrogen	Forest	30m (98 ft) to remove 97-100% (Doyle et al. 1975; Pinay and Decamps 1988)		
				Nitrogen and phosphorous	Not specified	36 m (118 ft) to reduce nutrients (Young et al. 1980)		
Mayer et al.	2006	Freshwater and wetlands	Summary of 14 regional reviews of riparian buffer literature	Nitrogen	Grass	4.6 – 27m (15 – 89 ft)– surface flow, -27-76% effective 10 – 100 m (33 – 328 ft) subsurface flow, 60-100% effective	>30 m (>98 ft) for effective reduction	Soil type, hydrology (flow paths), and subsurface biogeochemistry (e.g., organic carbon supply, high nitrate inputs) influence nitrogen removal in subsurface flows. Surface flows primarily remove nitrogen effectively when buffers are wide enough and sufficiently vegetated to control erosion and filter particulate nitrogen forms. Vegetation type (e.g. grass, trees, etc.) influences interception potential; for example, grass buffers are better at trapping sediment, filtering sediment-borne nutrients, and reducing sheet flow.
					Grass forest	7.5 – 15 m (25 – 49 ft) – surface flow, 28-41% effective 6 – 70 m (20 – 230 ft) – subsurface flow, 91-99%		
					Forest	30 – 70 m (98 – 230 ft) – surface flow, 78-79% 10 – 220 m (33 – 722 ft) subsurface flow, 58-100%		
					Forest wetland	5.8 – 38 m (19 – 125 ft) – subsurface flow, 59-100%		
					Wetland	20 m (66 ft) – surface flow, 12-74% 1 – 200 m (3.28 – 656 ft) – subsurface flow, 52-100%		
Hawes and Smith	2005	Freshwater streams		Nitrogen and phosphorus		4.9 – 50 m (16-164 ft)	5-30 m (16 – 98 ft) of dense grassy or herbaceous buffers on gradual slopes	Wider buffers will be able to provide longer-term storage. Nitrogen is more effectively removed than phosphorous. Greater widths necessary for steeper slopes
				Pesticides		15 – 100 m (49-328 ft)		

Appendix E

- Table showing literature summary documenting the impacts of urbanization, agriculture, and forest practices on riparian functions

Land use impacts on riparian function (Development, Agriculture and Forestry)

Land use	Riparian function impaired							Specific activities associated with land use category	Impact findings on function	Literature cited
	Water Quality	Shade/Microclimate	LWD	Litter fall	Fine sediment control	Wildlife	Hydrology/ slope stability			
Development	X	X	X	X	X	X	X	Clearing and grading/vegetation removal Construction of homes, buildings, roads/Impervious surfaces Shoreline armoring (docks, bulkheads, etc.) Landscaping (non-native plants) Recreational activities (hiking, biking, beachcombing, etc.)	Riparian areas are more highly altered in developed landscapes than in agricultural and forested landscapes	Booth 1991 (*in* Everest and Reeves 2006)
									Direct alteration within the riparian area (vegetation removal/reduction, soil compaction, grading) causes changes in loading of nutrients, organic matter and sediments; reduces capacity of riparian area to filter/absorb pollutants; increases sediment loading	Valiela et al 1992; Wahl et al. 1997; Jones et al. 2000; Jordan et al. 2003 (*in* Hale et al. 2004)
									Creation of impervious surfaces (e.g., parking lots, paved streets, sidewalks, roads), vegetation removal, and soil compaction cause surface water to increase in volume and magnitude. Increased runoff decreases the ability of soils and vegetation to infiltrate and intercept pollutants , increases flooding potential.	Knutson and Naef 1997; Montgomery et al. 2000 (*in* Johannessen and MacLennan 2007); Glasoe and Christy 2005; Hashim and Bresler 2005; Ekness and Randhir 2007; Schiff and Benoit 2007
									Construction of boat landings, docks, and piers creates increased slopes, causing increased and concentrated water flows; construction of domestic, residential and industrial facilities and utilities in and near riparian areas can result in altered topography, removal of vegetation, and rerouting of surface and groundwater flows	Knutson and Naef 1997; NRC 2002; Ekness and Randhir 2007; Schiff and Benoit 2007
									Construction close to the water's edge (bulkheads, docks, etc.) reduce shade as well as species diversity and abundance	Sobocinski et al. 2003; Rice 2006
									Areas with high levels of impervious surface coverage (>50%) correlated with low macrobenthic diversity and abundances	Lerbert et al. 2000
									Vegetation removal causes decreased shade and increased temperatures	Beschta et al. 1987; Macdonald et al. 1994; 1995; Thom et al. 1994; Penttila 1996; Williams and Thom 2001; Bereitschaft 2007
									Removal of vegetation cover also reduces LWD and canopy cover, which serve to dissipate flow energy and control temperature by shading	Booth et al. 2006
									Increases of light levels in the upper intertidal zone results in higher levels of mortality and dessication of insects, invertebrates, and the eggs of intertidal spawning fish like Pacific sand lance and surf smelt.	Pentilla 1996, 2000; Rice 2006
									Low levels of organic litter and LWD have been found on armored beaches	Sobocinski et al. 2003; Dugan and Hubbard 2006; Defeo et al. 2009
									Increased surface runoff of toxins Toxins can affect wildlife through physiological and behavior changes,	Klapproth and Johnson 2000; Krebs and Bums 1977; Krebs and Valiela 1978; Moore et al. 1979

Appendix G

- Summary table of buffer width recommendations from reviewed literature

APPENDIX G. A summary of buffer width recommendations from Appendix C.

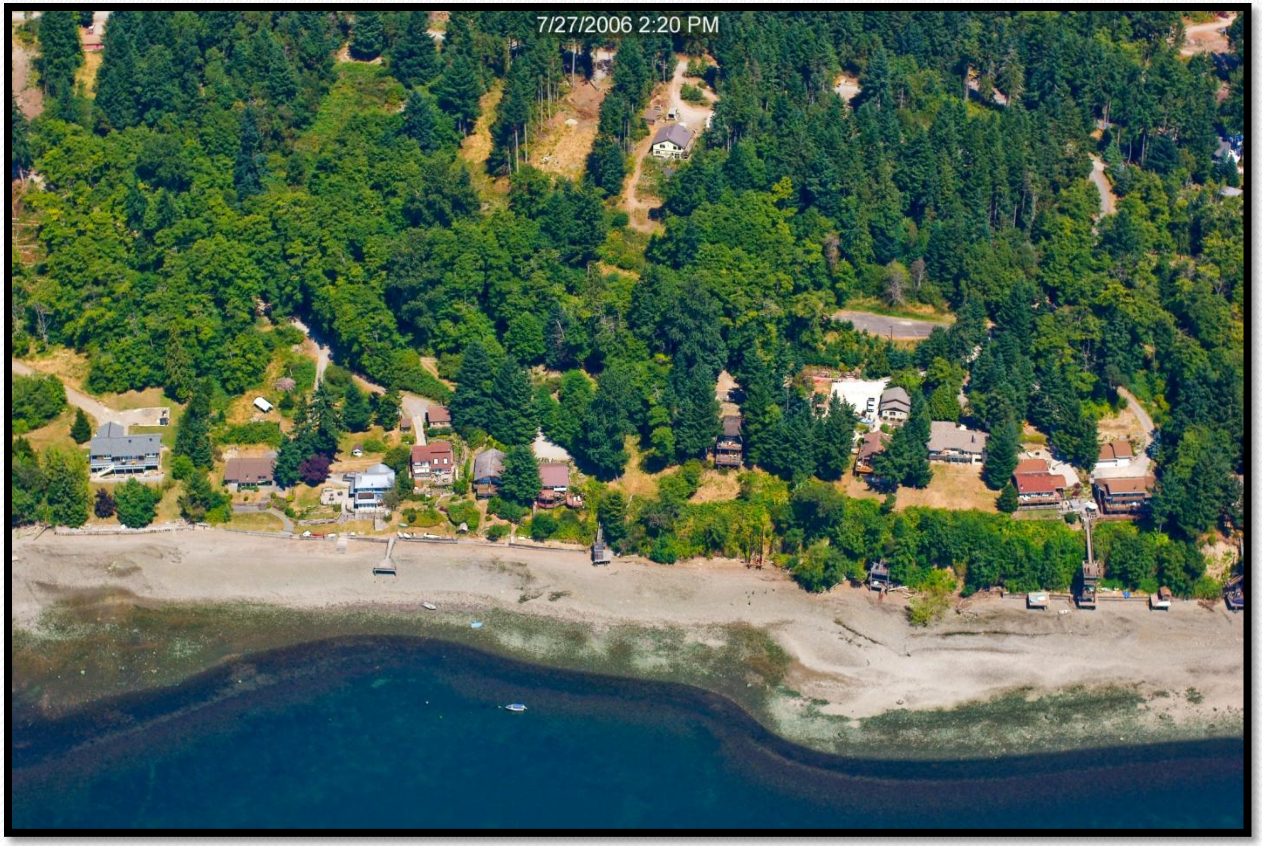
See Section II for a description of how this table was created.

Function	Buffer width recommendation to achieve ≥ 80% effectiveness	Literature cited	Average of all literature (to achieve ≥ 80% effectiveness)	Minimum buffer width (approximate) based on FEMAT curve to achieve ≥ 80% effectiveness
Water quality	5-600 m (16 – 1,968 ft) (Appendix C contains specific buffer widths for different water quality parameters)	5 m (16 ft): Schooner and Williard (2003) for 98% removal of nitrate in a pine forest buffer 600 m (1969 ft): Desbonnet et al (1994/1995) for 99% removal	109 m (358 ft)	25 m (82 ft) sediment 60 m (197 ft) TSS 60 m (197 ft) nitrogen 85 m (279 ft) phosphorus
Fine sediment control	25-91 m (92 – 299 ft)	25 m (82 ft): Desbonnet et al (1994/1995) for 80% removal 91 m (299 ft): Pentec Environmental (2001) for 80% removal	58 m (190 ft)	25 m (82 ft) (sediment) 60 m (197 ft) (TSS)
Shade	17-38 m (56 – 125 ft)	17 m (56 ft): Belt et al 1992 *IN* Eastern Canada Soil and Water Conservation Centre (2002) for 90% 38 m (125 ft): Christensen (2000) for 80% temperature moderation	24 m (79 ft)	37 m (121 ft) (.6 SPTH*)
LWD	10-100 m (33 – 328 ft)	10 m (33 ft): Christensen (2000) for 80-90% effectiveness 100 m (328 ft): Christensen (2000)	55 m (180 ft)	40 m (131 ft) (.65 SPTH*)

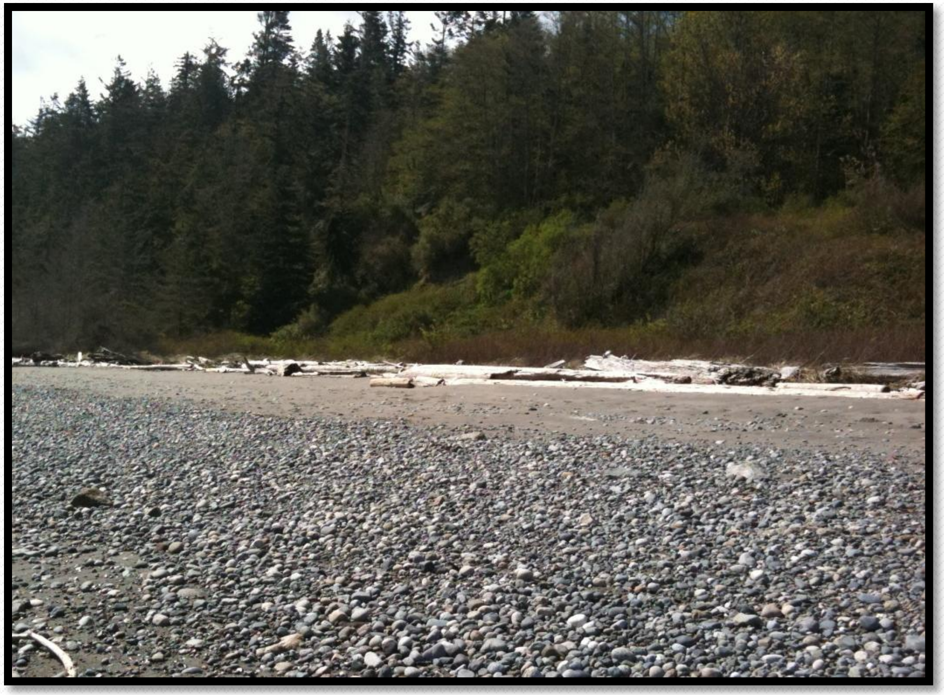
Impacts of Development

Modern development along marine shorelines usually involves the removal of native vegetation, topsoil and organic matter and the compaction of soils which result from clearing and grading, construction of buildings, pavement, and roads. Additional impacts include the introduction of nonnative plant species associated with landscaping. Loss of natural vegetation in riparian and stream habitats in developed areas is usually permanent, (Booth 1991 in Knutson and Naef 1997) and activities associated with development impact all riparian functions (See Appendix E, Tables 1-2).

How can impacts of development on marine riparian functions be minimized?



- Avoid vegetation removal on shorelines and bluffs.
- If vegetation must be removed, minimize the area and amount removed and locate the disturbed area as far from the water as possible.
- Minimize ground disturbance, removal of mature trees, and introduction of nonnative vegetation, especially invasive species such as English Ivy.



- Avoid locating impervious surfaces in riparian buffers.
- If impervious surfaces must be located in riparian areas, minimize footprint, and mitigate impacts through techniques including pervious surfaces such as pervious pavers and concrete; bioretention facilities such as rain gardens; green roofs, cisterns, etc.
- Promote infiltration and implement approved methods/designs for controlling rates of surface runoff and pollutant loading.
- Caution should be taken when designing and installing bioretention and other facilities that infiltrate water along slopes and bluffs so as to not increase the likelihood of mass failures or erosion.

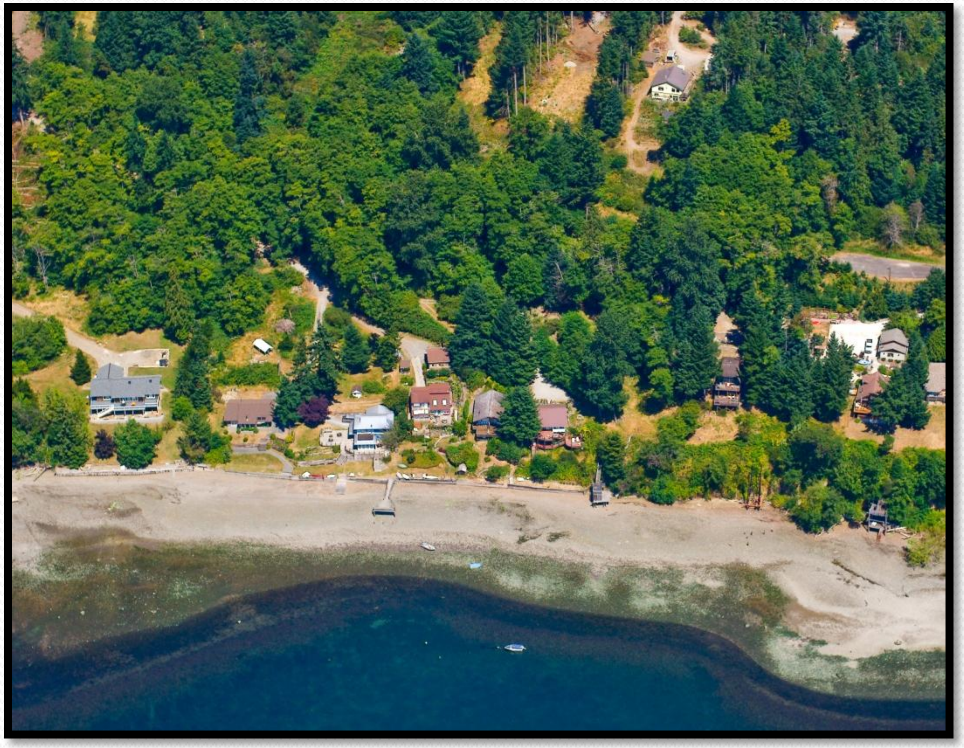
- Avoid shoreline modification; maintain existing native vegetation, particularly at and near the land-water interface.

- If shoreline alterations must occur they should be done in a way that minimizes potential negative impacts to natural functions and should use the least intrusive methods including bioengineering or relocating structures where feasible and practicable.

- All adverse impacts should receive full compensatory mitigation to ensure no net loss of ecological functions.

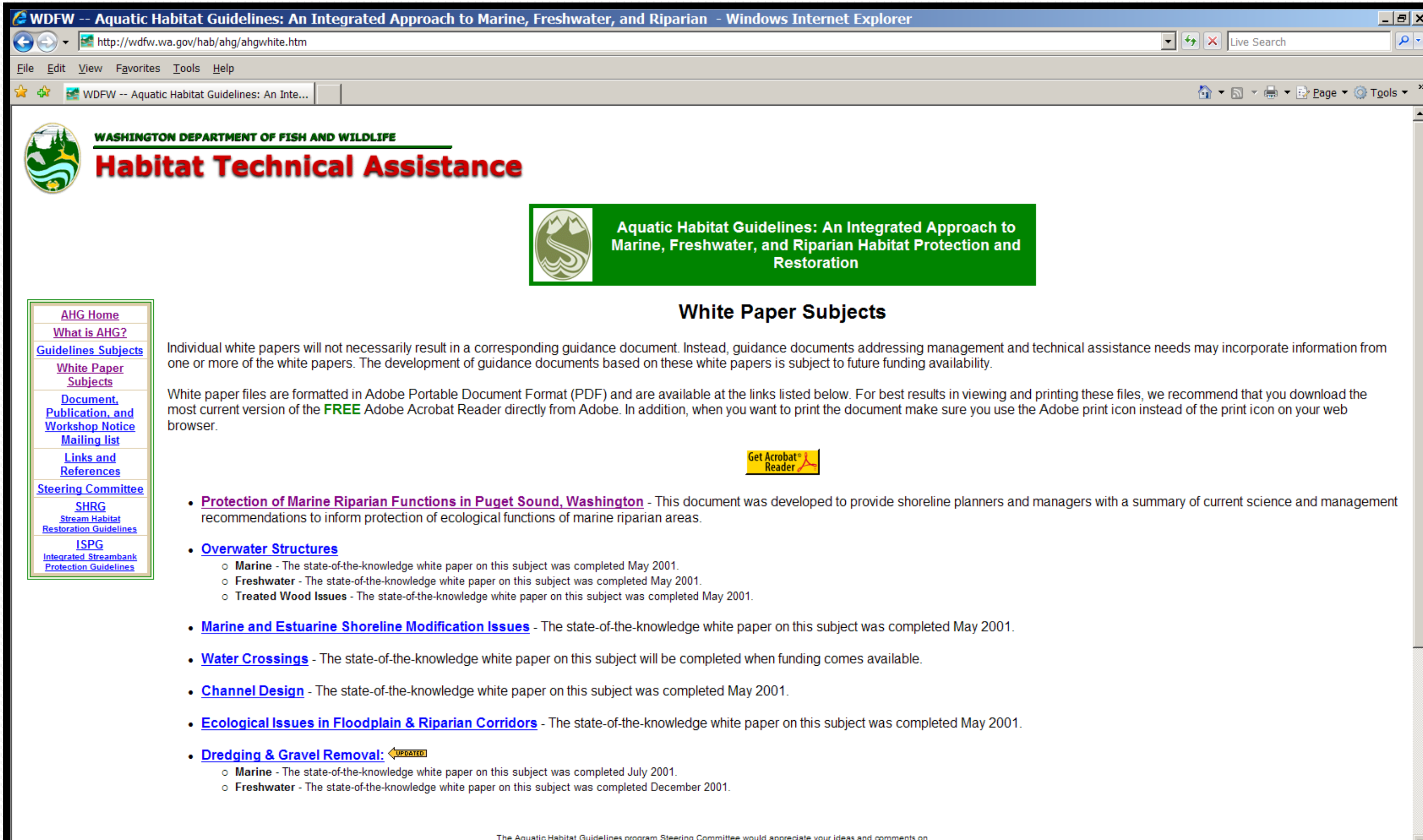
- Avoid locating septic and waste water systems in the riparian area.

- If they must be located in the riparian area, then they should be designed, maintained, and operated in such a way that that human waste and nutrients are prevented from leaching into local water bodies.



- Avoid land use practices in riparian areas that involve the use or generation of nutrients, pathogens, and toxics.
- Avoid salvage or removal of downed trees, wood or snags in riparian areas and on beaches.

http://wdfw.wa.gov/hab/ahg/



Questions?